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**Slope Failure, Tectonics, and Gas+Fluid Expulsion on the Southern Cascadia
Continental Shelf and Slope: Effects on Seafloor Geomorphology**
(ONR grant: N00014-96-1-0361)

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Long Term Goal

The long term goal of this project is to understand how tectonics, gas, and hydrogeology interact as forcing agents in the creation and modification of submarine geomorphology.

Scientific Objectives

The objective of this project is to evaluate the role of fluid flow, overpressuring, and gas migration in the creation of failure features on the seafloor of a tectonically active continental margin. This project addresses questions about the lateral and vertical extent of detectable gas and gas-related structures in the subsurface, the regional distribution of failure features, the locations of overpressured fluids in the subsurface, and how the structural geology of this region affects the locations of gas+fluid migration pathways and expulsion sites. We pursue answers to these questions using a combination of theoretical and observational analyses. Observations and hypotheses based upon remote sensing techniques (industry-quality multichannel seismic, high resolution multichannel seismic, high resolution single channel seismic, acoustic reflectivity, high resolution sidescan, high resolution bathymetry) will be ground-truthed with direct observation and sampling via use of a remote operated vehicle (ROV). These observations will become the basis for modeling the relationship between gas-charged fluids and slope failure. Fulfillment of these objectives will allow us to obtain a better understanding of the dynamic processes occurring on the southern Cascadia continental shelf and slope, and ultimately help address how sediment is transported from the shelf to upper slope, and from the upper slope to abyssal depths.

Background

Our recent studies have focused on seepage-induced spring sapping, where excess pore pressure gradients trigger slope failure. The Eel River basin (Figure 1a) is a prime study area because it has all the ingredients necessary for fluid overpressuring at depth: tectonic compression, sediment loading, and hydrocarbon formation. Coastal tectonic uplift and high erosion rates create conditions conducive to rapid and voluminous deposition of organic-rich sediments into the offshore Eel River basin. Data collected from the region show evidence of both active gas+fluid expulsion and the presence of submarine landslides.

Sediments entering the Cascadia accretionary complex may initially contain over 50% water; during accretion this may be reduced to less than 10% by compaction, cementation and deformation. Thus, substantial amounts of pore fluid are either trapped in overpressured zones, or liberated to the seafloor, migrating to the surface along permeable fault zones, stratigraphic layers, mud diapirs and mud volcanoes. The initial pore fluid (seawater) may be augmented by exotic constituents, such as hydrogen sulphide, natural gas, or oil derived both from deeper sediments and devolatilization reactions. Thermogenic and biogenic gas in the Eel River basin travel dissolved in fluids along faults and permeable stratigraphic horizons until a saturation point is reached and the gas comes out of solution.

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Such free gas can contribute greatly to the overpressuring and expulsion of fluids, and may play a significant role in shaping seafloor morphology. Gas and/or overpressured fluids may trigger submarine landslides because they provide a buoyancy force that offset the gravitational forces acting down on a column of sediment. Overpressured fluids can have dramatic effects on faulting at depth, the creation of mud diapirs and mud volcanoes, and slope failure at the surface. Because they originate in overpressured zones at depth and rise toward the surface, mud diapirs/volcanoes can provide an efficient conduit for fluid expulsion from depth. In the Eel River basin, our data show mud diapirs (Figure 2) and possibly mud volcanoes, indicating potential locations of gas and fluid expulsion.

Analysis of seismic, sidescan, and high-resolution bathymetry data allows us to correlate the locations of subsurface gas with expulsion-related features observed on the seafloor.

Approach

Given the setting of the Eel River basin as a region ripe for fluid expulsion, and our suspicion that gas has an effect on slope stability, we have been analyzing seismic data for the presence and distribution of gas and overpressured fluids in the subsurface to see how it correlates with the presence of slope failures. We first use industry-quality multichannel seismic data (Figure 1) to determine the regional structural trends within the offshore Eel River basin and document the general distribution of gas, gas-related features (e.g. mud volcanoes, breached anticlines, or diapirs), and overpressured fluids. Gas dispersed in the subsurface obstructs the passage of acoustic waves, resulting in acoustically blank areas, or it may pool at the crest of an anticline (Figure 2), causing a strong negative polarity reflector. Negative polarity reflectors may also indicate zones of overpressured fluids. We can thus compare the distribution of gas and overpressured fluids with large-scale failure features noted on high resolution bathymetric and acoustic reflectivity data. Use of high resolution sidescan and high resolution seismic data can facilitate documentation of localized areas of fluid seepage sites and finer-scale surface failure features. Observations made using these data sets will be used to locate potential ROV deployment sites, as well as provide us with a framework for geologic modeling.

Accomplishments and Results

Evidence of abundant gas and numerous surface failure features in the offshore Eel River basin strongly suggests a causative link between gas+fluid expulsion and morphologic features on the seafloor. Our preliminary studies using industry-quality multichannel seismic data show that gas abundance is regionally variable throughout the Eel River basin (Figure 3), and areas containing the most gas can be correlated with seafloor failures seen using other techniques. We used high resolution bathymetry, high resolution sidescan, and high resolution seismic data to infer the presence of gas at and below the seafloor. We plan to ground-truth our inferences regarding the presence of gas and fluid expulsion using an ROV for seafloor mapping and sampling.

Data from multichannel seismic lines (Figure 1b) show that although subsurface gas is abundant in this region, it is regionally variable and is more closely correlated with total water depth than with underlying structure. Acoustically transparent (wipeout) areas are observed within some anticlines and diapirs, but not all wipeouts are necessarily correlated with such structures. Preliminary analysis of high resolution Hunttec and 3.5 kHz seismic records show gas plumes in the water column occurring at depths near 100m water depth, with subsurface gas often occurring in coincident areas. Bright spots, gas columns in the sediment, and bottom simulating reflectors (BSR) are also observed in this region, as is a shore-parallel wipeout zone occurring at depths between 100-250m. The head of the Humboldt slide lies within this wipeout zone, suggesting the presence of abundant gas may be related to landslide initiation. BSRs are observed in some locations in water depths greater than 750m, and the dissociation of gas hydrate in this tectonically active area may

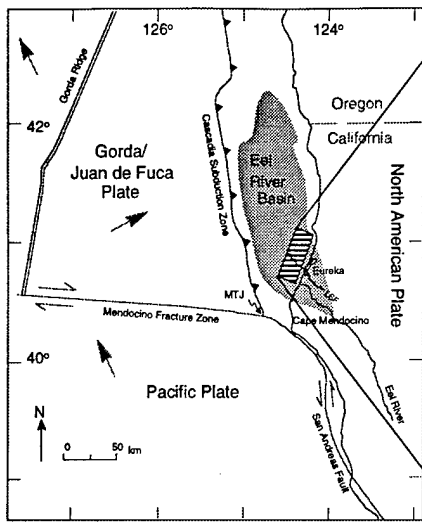


Figure 1a

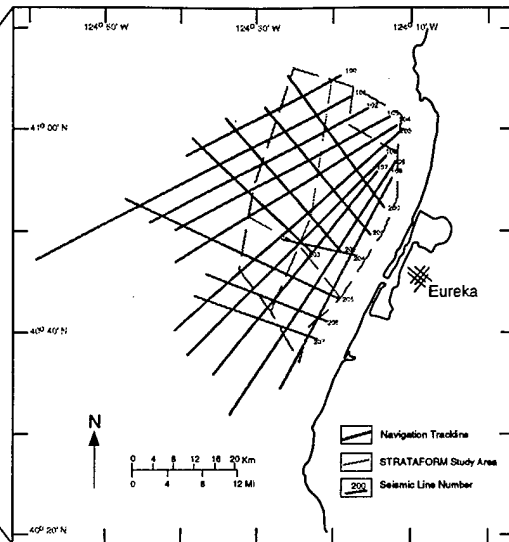


Figure 1b

Figure 1a. Location map of the northern California margin, showing location of Gorda/Juan de Fuca, Pacific, and North American plates. Large arrows indicate relative directions of plate motion. Shaded box in the Eel River basin depicts approximate extent of STRATAFORM study area. MTJ: Mendocino Triple Junction. LSF: Little Salmon Fault. (Figure modified from Clarke, 1992).

Figure 1b. Map showing locations of Jebco/Amoco multichannel seismic ship track lines (solid lines) and STRATAFORM study area (dashed lines).

Figure 2. Representative seismic line showing inferred mud diapir (location A). In this same line, gas trapped at the crest of the truncated anticline may be the cause of a high amplitude "bright spot" (location B). Every 100 shotpoints = approximately four miles. Seismic data provided by Amoco Corp. and acquired by Jebco Geophysical.

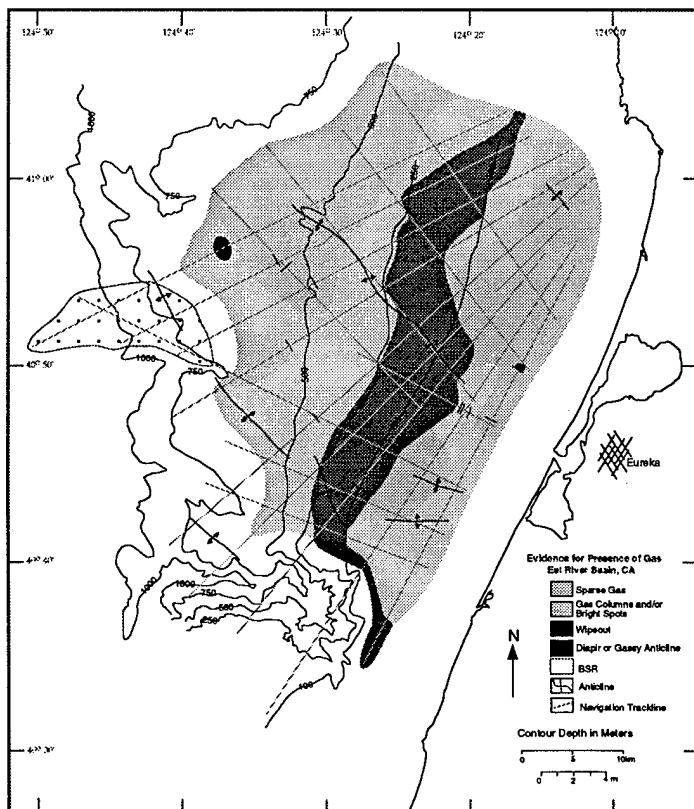
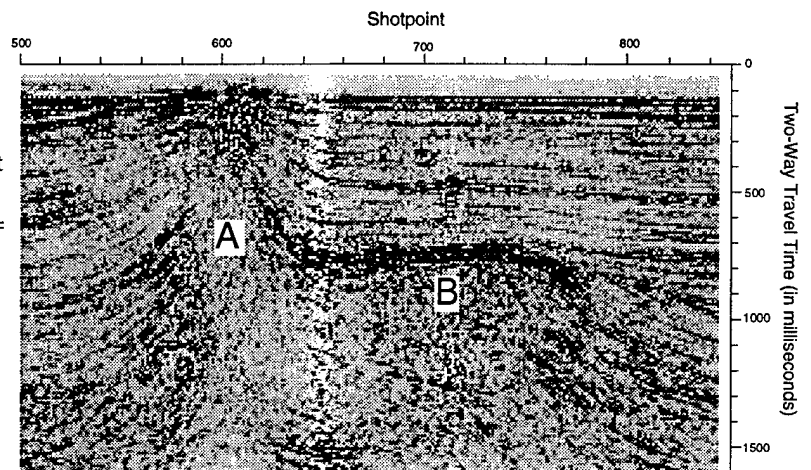


Figure 3. Map showing gas distribution in the Eel River basin. Abundant gas effectively attenuates passing acoustic waves, resulting in data "wipeouts". A bottom simulating reflector (BSR) in the seismic lines suggests the presence of methane ice in this area as well. Note the correlation of gas abundance with depth. Locations of navigation tracks are indicated by dashed lines.

also contribute to slope instability. Pockmarks have been noted on both sidescan and high-resolution bathymetry surveys, and we believe these to be related to gas and fluid expulsion events. Presently we are cataloging these findings and creating a database that will enable us to easily compare data sets.

Scientific Impact and Transitions Accomplished

Our preliminary studies show abundant subsurface gas and evidence of gas+fluid expulsion in areas containing surface failure features, which strongly suggests a causative link between gas and changes in submarine geomorphology. Given that natural gas is a common occurrence on continental shelves worldwide, results from this project should be suitable for extrapolation to other areas, especially in sedimentary basins that experience high sedimentation rates and/or are near tectonically active margins.

1996 Publications Supported by ONR

Austin, J.A., Fulthorpe, C.S., Mountain, G.S., Orange, D., and Field, M.E., 1996, Continental margin seismic stratigraphy: assessing the preservation potential of heterogeneous geologic processes operating on continental shelves and slopes; in press, *Oceanography*.

Syvitski, J.P., Alexander, C., Field, M.E., Gardner, J.V., Orange, D.L., and Yun, J.W., 1996, Continental-slope sedimentation: the view from Northern California; in press, *Oceanography*.

Yun, J.W., Orange, D.L., and Moore, J.C., 1996, Changes in seafloor morphology due to gas migration in the Eel River Basin, CA: observations using multichannel seismic images; in *Geological Society of America Abstracts with Programs*, vol. 28, no. 5, p. 128.

Yun, J.W., Field, M.E., and Orange, D.L., 1996, Gas in the Eel River Basin and its link to geomorphic changes on the seafloor of the continental margin; to be published in *American Geophysical Union 1996 Fall Meeting Abstracts with Programs*.

Abstract

Evidence of abundant gas and numerous surface failure features in the offshore Eel River basin strongly suggests a causative link between gas+fluid expulsion and morphologic features on the seafloor. Our preliminary studies using industry-quality multichannel seismic data show that gas abundance is regionally variable throughout the Eel River basin (Figure 3), and areas containing the most gas can be correlated with seafloor failures seen using other techniques. We used high resolution bathymetry, high resolution sidescan, and high resolution seismic data to infer the presence of gas at and below the seafloor. We plan to ground-truth our inferences regarding the presence of gas and fluid expulsion using an ROV for seafloor mapping and sampling.

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